SPECTRAL VARIABILITY OF SUPERGIANT HD 21389

K. Pivoňková [a*], ***O. V. Maryeva*** [b], ***A. Aret*** [c], ***V. Checha*** [c]

[a] *Department of Theoretical Physics and Astrophysics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic*

[b] *Astronomical Institute of the Czech Academy of Sciences, Fričova 298, 25165 Ondřejov, Czech Republic*

[c] *Tartu Observatory, University of Tartu, Observatooriumi 1, 61602, Tõravere, Tartumaa, Estonia*

Late B- and early A-type supergiants are interesting evolved stars exhibiting photometric variability accompanied by spectral changes. Particularly interesting is a group of pulsating stars named after Deneb as α Cyg variables. Deneb-type variables are known for decades to show variability in both brightness and radial velocities. Despite this group of stars undergoing continuous observations, the mechanism responsible for such changes is not yet well understood. In order to better understand and possibly describe this mechanism, the continuous spectral monitoring of early-type supergiants is still a topical task. The main goal of our work is to characterize the spectral variability of one of the Deneb-type variables – HD 21389. We carried out the spectral variability analysis of its spectra taken within 6 years from 2017 up to now.
Radial velocities and lines' profiles of HD 21389 show variability across the whole observational period with the most prominent variability in the Hα line. Among other things, we captured the final phase of the High-Velocity Absorption event (HVA) which HD 21389 underwent in 2018, and observed broad emission features around Balmer lines.

Keywords: stars: early-type – stars: massive – stars: individual: HD 21389 – stars: atmospheres – techniques: spectroscopic – techniques: radial velocities

1. INTRODUCTION

Late B- and early A-type supergiants represent a progressive evolutionary phase of massive stars that are evolving redward after they leave the Main Se-

* E-mail: pivonkova@mail.muni.cz

quence (MS) or already underwent the Red Supergiant (RSGs) stage and moving blueward in their second crossing of Hertzsprung–Russell (H–R) diagram.

Among these stars is a group of variables, called Deneb (or α Cyg) type variables named after its prototype, and exhibiting low amplitude photometric variability ($\Delta V \leq 0.1$ mag) and variability in radial velocity with period 1.2 – 100 days, as well as the variability of spectral lines' profiles [1]. With their quite short lifetime (ranging from several to tens of millions of years), which leads to an unbalanced final stage in form of a core-collapsed supernova (SN), these objects are rare. Because of their significant variability, we need to know more about them.

HD 21389 is an A0 type supergiant located in Cam OB1 association (e.g., [2]) and included in a list of Galactic α Cyg variables (e.g., [3]). The main parameters of HD 21389 are listed in Table 1.

The story of the HD 21389 started more than one century ago, in 1910 when Mr. Young performed spectroscopic observations and analysis of its spectra ([4]). Based on these results, the star was suggested as a spectroscopic binary [5]; however, its binarity has never been reliably confirmed. The vast majority of previous studies (e.g., [7–9]) discuss variability in radial velocities and profiles of Balmer lines (mainly Hα and Hβ) that is strongly tied to the active phase. Some studies (e.g., [6, 7, 10, 11]) also revealed variability in metallic lines.

The most extended spectral study of this star was performed by Corliss et al. [14]. Authors analyzed 152 spectra taken with the 1-m telescope of Ritter Observatory between 1993 and 2007 and detected High-Velocity Absorption (HVA) events in spectra from the years 1993-1994. Their study also presents results based on simultaneous photometric observations, that show a strong correlation between photometric and spectroscopic variability with active and quiescent phases of the star. In this paper, we study the spectroscopic variability of HD 21389 using a set of new spectral observations covering 6 years. Our analysis revealed variability in radial velocities, and lines' profiles, and also brought new results such as the presence of extended emission wings around the Hα line, as well as the detection of another episode of HVA.

2. OBSERVATIONS AND SPECTRAL DATA REDUCTION

Optical spectroscopic observations of HD 21389 mainly in Hα region were performed during 6 years from 2017 up to 2022 at the Perek 2-m telescope of Czech Academy of Science and AZT-12 1.5-m telescope of Tartu Observatory, University of Tartu, Estonia. Spectroscopic observations performed at the Perek 2-m telescope were done using two spectrographs: Single order spectrograph (CCD700) [15] and Ondřejov Echelle Spectrograph (OES) [16, 17].

Table 1. Stellar parameters for HD 21389.

Parameters	Values	References
Names	HR 1040, CE Cam, BD+58 607	
RA (J2000)	$3^h29^m54.74^s$	[17]
Dec (J2000)	$58°52'43.5''$	[17]
M_V [mag]	-7.56	
V [mag]	4.54	[29]
B [mag]	5.10	[29]
Spectral Type	A0 Ia	[2]
Parallax [mas]	0.930 ± 0.119	[17]
T_{eff} [K]	9730	[31]
M [$M_\odot$]	19.3	[31]
R [$R_\odot$]	97	[31]
$\log L/L_\odot$	4.87	[33]
$\log g$ [cgs]	1.7	[28]
v_{esc} [$km \cdot s^{-1}$]	233	[12]
$v \cdot sin\, i$ [$km \cdot s^{-1}$]	53	[31]
$\dot{M}$ [$M_\odot \cdot yr^{-1}$]	$-4.2 \cdot 10^{-7}$	[32]
Distance [pc]	1084^{+124}_{-112}	[30]

Both spectrographs are connected to the primary focus by optical fiber and placed in separate rooms. Observations at the Tartu observatory were carried out using a Single slit spectrograph (ASP-32) that is directly attached to the Cassegrain focus [18]. The information about spectra used in the work is given in Table 2.

Data from ASP-32 and OES spectrographs were processed using standard IRAF tasks, while spectra taken by the CCD 700 instrument were reduced using a dedicated IDL-based package including all standard steps. Additionally, the telluric correction was done using MOLECFIT 1.5.1. software [19, 20]. All spectra are normalized and corrected for barycentric velocity.

Table 2. Summary of spectral data used in present work. R is spectral resolution, N is number of spectra.

Telescope	Instrument	R	Sp. range [Å]	Obs. period	N
Perek 2m	CCD700	13 000	6260 – 6730	Aug 2017 - Aug 2022	86
	OES	50 000	3965 – 8740	Jul 2021 - Oct 2021	10
AZT–12	ASP–32	10 000	6300 – 6580	Aug 2018 - Nov 2021	30

3. RESULTS

In total, we performed a spectral analysis of 126 spectra of HD 21389. The sample spectrum taken on Sep 26, 2018, may be seen in Fig. 1. We mainly focused on the study of the variability of Hα line profile, but we also measured radial velocities of selected absorption lines listed in Tab. 3 to test possible binary behavior and to trace the motion of matter in the atmosphere of the star.

Fig. 1. Spectrum of HD 21389 taken on Sep 26, 2018 in Hα region with Perek 2m, CCD700. Telluric lines are removed from the spectrum using MOLECFIT.

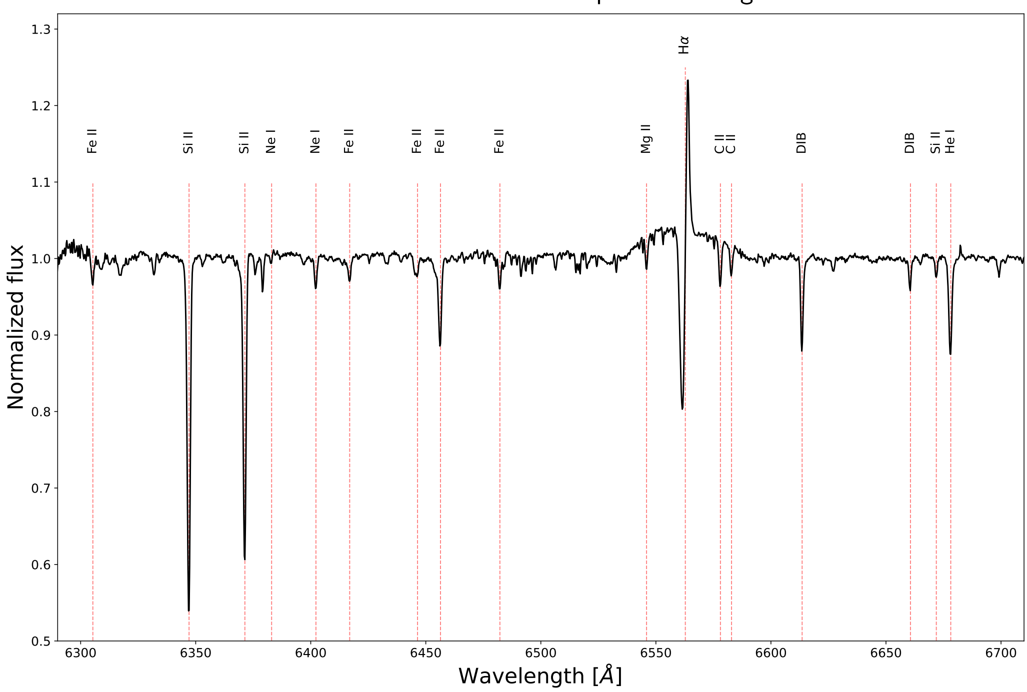


Table 3. List of spectral lines of which the radial velocities were measured (λ is air wavelength).

Spectral line	λ [Å]	D700	ASP-32	OES	Spectral line	λ [Å]	D700	ASP-32	OES
Si II	6347.11	✓	✓	✓	DIB	6613.56	✓		
Si II	6371.37	✓	✓	✓	DIB	6660.64	✓		
Fe II	6456.38	✓	✓	✓	Hβ	4861.32			✓
Mg II	6545.94	✓	✓	✓	Hγ	4340.46			✓
Hα	6562.80	✓	✓	✓	Hδ	4101.73			✓
C II	6578.05	✓		✓	Na I	5889.95			✓
C II	6582.88	✓		✓	Na I	5895.92			✓
He I	6678.15	✓		✓					

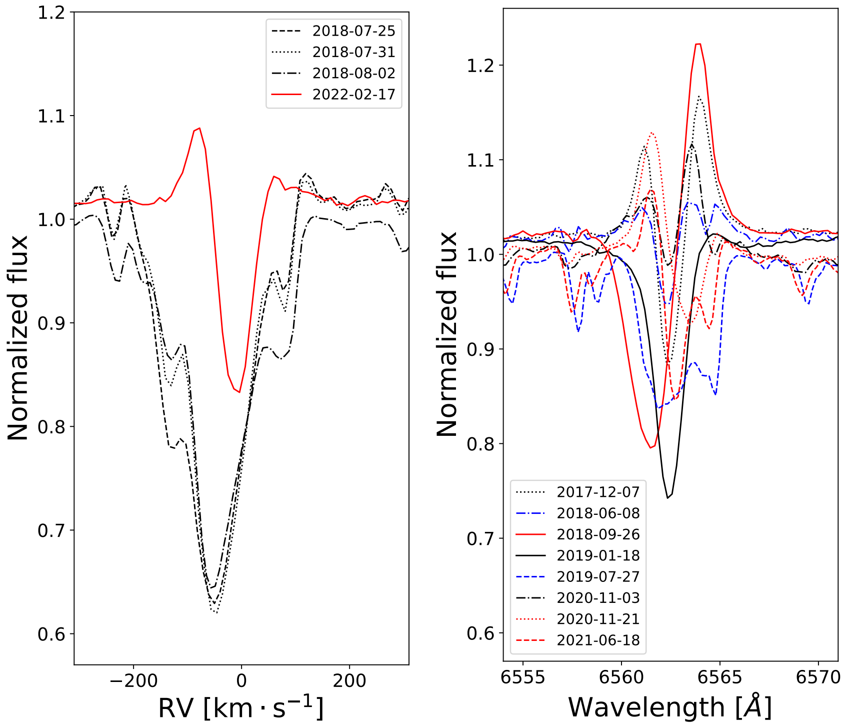
3.1. Variability in Hα line

As it is known, the best indicator of stellar wind in B- and A- type supergiants is Hα line [22]. Hα line in HD 21389 spectrum has a complex structure and displays significant variability across all our observations. Pure absorption, normal and inverse P Cyg, and double-peaked profiles were observed. Sometimes highly asymmetric profiles appear, but in our case, that was associated with fading of the HVA event (the left panel of Fig. 2). Selected lines' profiles are shown in the right panel of Fig. 2.

3.1.1. High-velocity absorption event

As was already mentioned in the introduction, HD 21389 is one of the rare stars showing high-velocity absorption events (HVAs) [14]. HVA event is the occasional appearance of deep and highly blue-shifted absorption component detected only in the Hα line. The kinematic properties of the HVAs are completely different from those of Discrete Absorption Components (DACs) observed in the ultraviolet spectra of O-type and early B-type stars. HVAs do not propagate outwards, but instead, extend to zero velocity and even indicate mass infall [21].

α Cyg variables with HVA events are rare. This behavior was already observed in a few late B- and early A- type supergiants HD 91619 (B7 Iae), HD 96919 (B9 Iae), HD 34085 (B8 Iae), HD 197345 (A2 Ia), HD 207260 (A2 Iab), and HD 199478 (B8 Iae) [24], [25], [21], [26], [27]. Such events are reported to last



(a) (b)

Fig. 2. (a) Lines' profile appearance during final phase of HVA event is demonstrated by black lines. Red solid line is to compare the intensity with profile taken out of HVA event. (b) Selected lines' profiles of Hα line.

from dozens of days to several months [21]. There is currently no proper explanation for the formation of HVAs. Israelian, Chentsov, & Musaev [23] attributed them to the effects of magnetic fields, but these stars do not have a such strong magnetic field to fit the observational properties of HVA.

Our data taken during July and August 2018 revealed the presence **of highly asymmetric**, unusually deep and blue-shifted absorption component of Hα line profile when the intensity reached 0.6 of continuum level (Figure 3). We detected only one HVA event in our spectra of HD 21389 acquired over 6 years. This indicates that conditions in the atmosphere of HD 21389 necessary for the appearance of HVA events require at least several years to form. However, there is evidence of two consecutive HVA for Rigel (HD 34085) just several months apart [23].

Since these events are associated with significant variability in the Hα line without any correlation in other lines, it may be said that the star switches between active phases represented by HVAs and quiescent ones containing no such events.

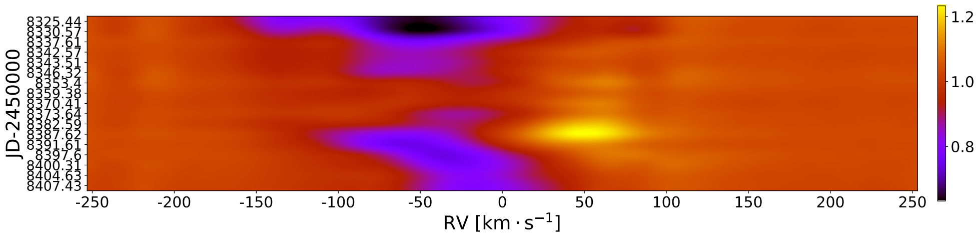


Fig. 3. Dynamic spectrum intercepting final phase of HVA that HD 21389 underwent during July and August 2018. Color bar at the right side represents the flux, thus the darkest part (top black region) shows HVA.

3.1.2. Broad emission wings around Hα line

All data contains a prominent feature of extended emission wings around the Hα line. Although HD 21389 has been spectroscopically studied many times before, especially the Hα region, no one has mentioned this feature. The emission wings extend to about $\pm 1400\,\mathrm{km \cdot s^{-1}}$ as shown in Fig. 4. We performed the analysis of this feature. Broad emission wings in a few spectra were fitted with Gaussian profile and it turned out that this feature varies on a timescale of a few weeks and from time to time appears asymmetric without any pattern.

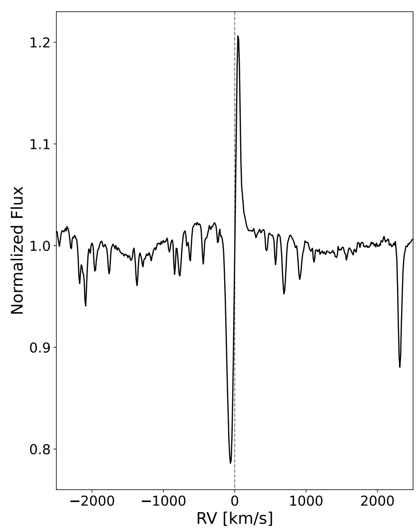


Fig. 4. Extended emission wings around Hα line.

3.2. Variability in other lines

All studied lines listed in Tab. 3 display variability in radial velocities (except the interstellar Na II doublet) across the whole observational period and also show asymmetries in lines' profiles while the most striking changes are recorded in Balmer lines, especially in the Hα line (Fig. 5).

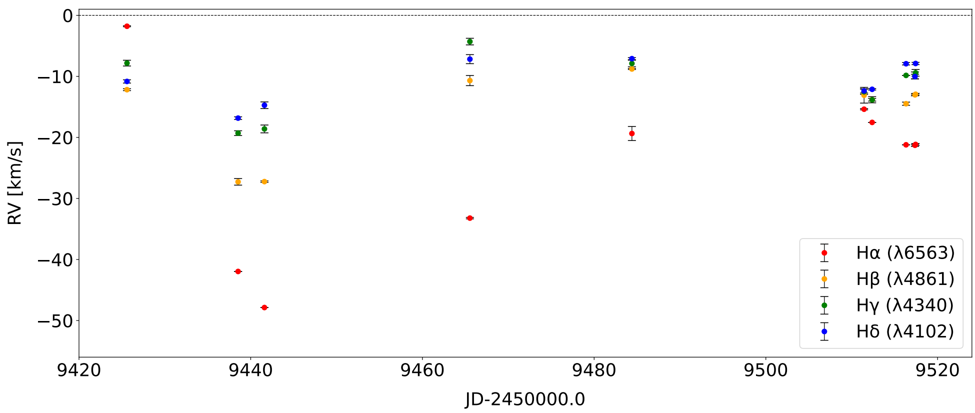


Fig. 5. Radial velocities of Balmer lines measured from OES spectra taken from July to October 2021.

In a study by Abt [11], the radial velocities of selected lines were measured. Among others, the surprising results were obtained for Si II λ4028, 4030 and Fe II λ4508, 4515, 4520, 4522 lines. Both velocity curves were almost the same in shape but slightly shifted in radial velocity. The same result may be seen in Fig. 6.

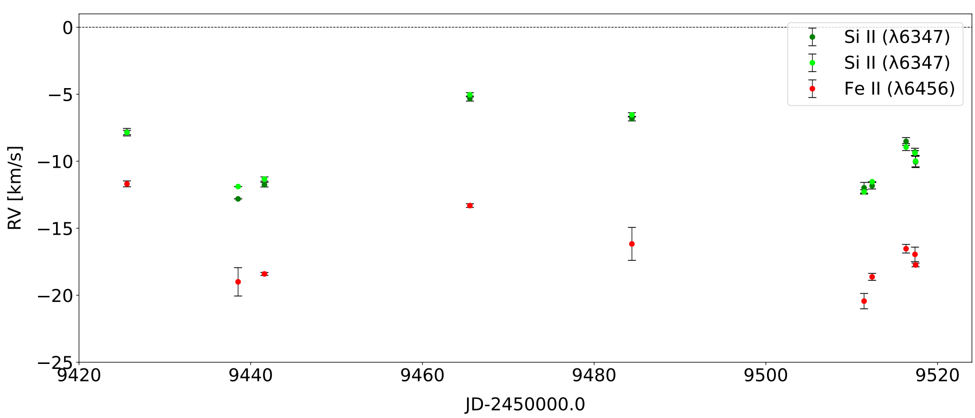


Fig. 6. Comparison of radial velocities of Fe II λ6456 and Si II λ6347; 6371 lines measured from the OES spectra.

Interesting results were obtained from the analysis of radial velocities of Mg II λ6546 line, see Fig. 7. The observations taken with AZT-12 telescope point to some signs of binarity with the period around 400 days, but we need more observational data to be sure.

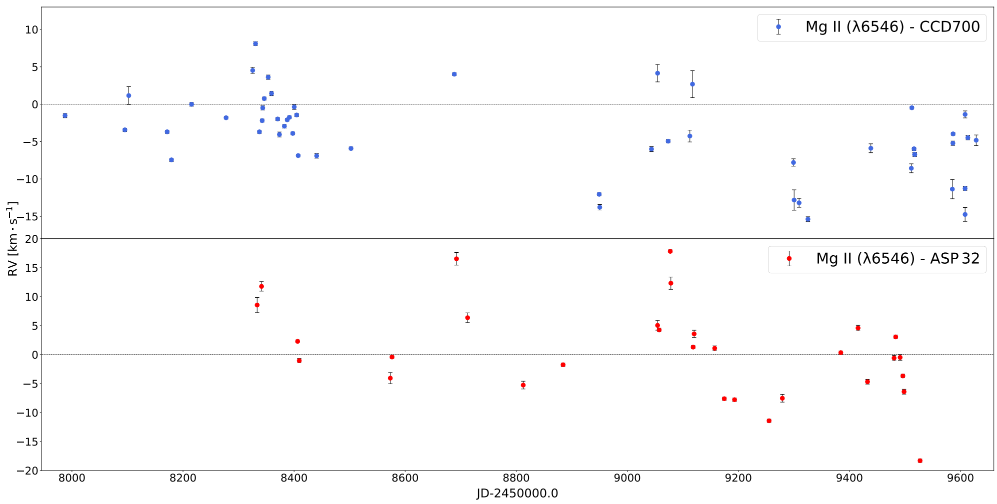
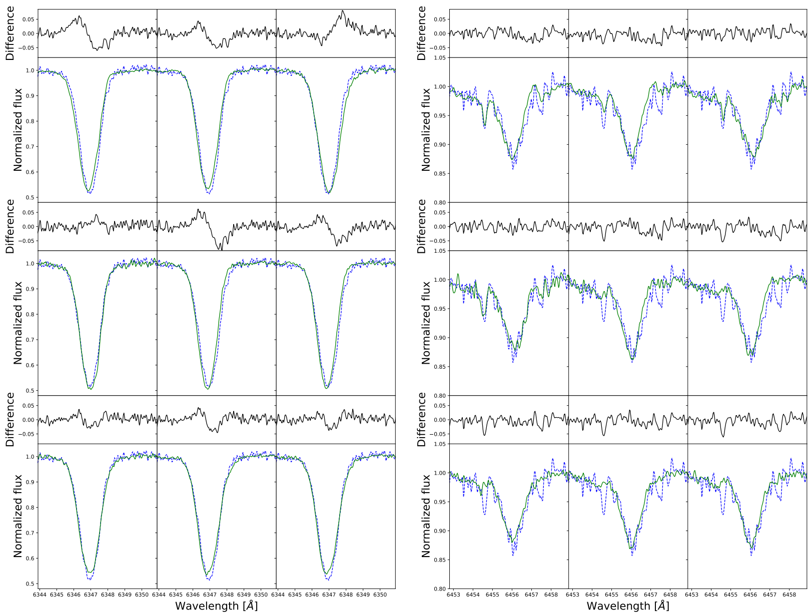


Fig. 7. Measured radial velocities of magnesium line Mg II λ6546. Blue dots represent data from CCD700 and red ones are data from ASP-32.

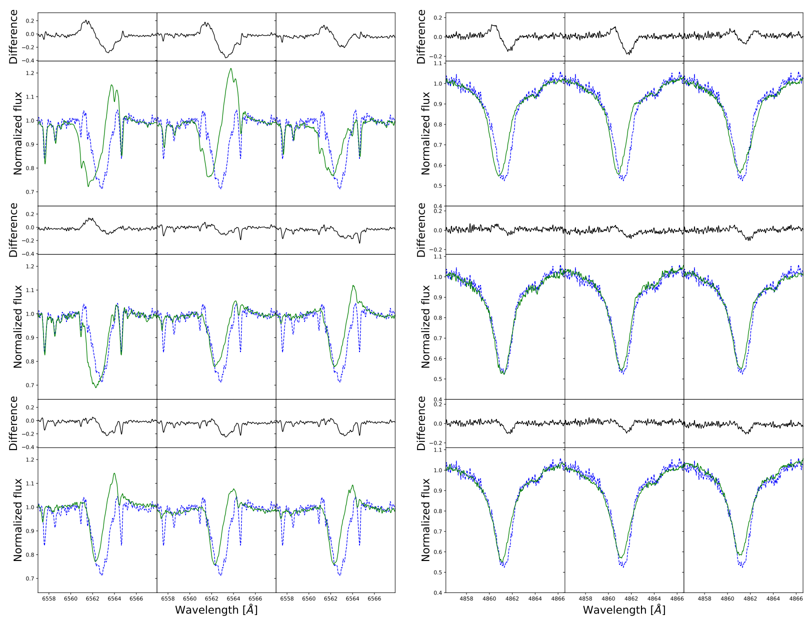
Spectra taken with OES have the largest wavelength coverage in our data set, which allows us to analyze other Balmer lines (Hβ, Hγ, Hδ, Hϵ). A sample of lines' profiles variability in OES spectra is shown in Fig. 8. As mentioned above, noticeable asymmetries are clearly seen in the Hα line profile (Fig. 8 (c)).

4. CONCLUSION

We analyzed spectral variability of A-type supergiant HD 21389 based on medium- and high-resolution spectra collected during 6 years. HD 21389 shows long-term variability (longer than a month) and variability on a short time scale (tens of minutes or several days) in both radial velocities and lines' profiles. The most striking changes were recorded for the Hα line. We observed variability with no obvious pattern in the width of extended emission wings and detected HVA (July and August 2018) during which the depth of the Hα line reached its maximum. All other measured lines show variability too. Asymmetry in lines' profiles reflects the actual condition of the Hα line which is associated with active or quiescent phases of the atmosphere.



(a) Si II (λ6347) (b) Fe II λ6456)



(c) Hα (λ6563) (d) Hβ (λ4861)

Fig. 8. Line profile variability of Si II, Fe II, Hα and Hβ lines. The blue dashed profile is a reference and the rest of the spectra compared to it are green. Their asymmetry is seen above (black line).

5. ACKNOWLEDGEMENT

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